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IDeA Labs: BYU's NSF CSUMS Program

Jeffrey Humpherys and Sean Warnick

1. Program Overview

The CSUMS program at BYU furthers the development of a network of interdisciplinary student-focused research laboratories that explore algorithmic decision processes from a common mathematical framework of information, dynamics, and control. These "Information and Decision Algorithm Laboratories," or "IDeA Labs," form a research model designed to demonstrate the power of mathematics to students by allowing them to abstract fundamental concepts such as approximation, optimization, and control from a diverse set of application domains.

IDeA Labs consists of four distinct laboratories, which are thematic centers for the study of algorithmic decision processes arising in various disciplines. They are:

- The Computational Biology and Environmental Systems Lab (CBES),
- The Computational Economics and Financial Systems Lab (CEFS),
- The Operations Research and Engineered Systems Lab (ORES),
- The Policy Sciences and Human Systems Lab (PSHS).

Each of these laboratories house research projects, invite collaborations, facilitate interaction with other research groups, and encourage partnerships with industry. Nevertheless, all the projects are focused abstractly on algorithmic decision processes and introduce students to the common mathematical themes underlying these problem areas.

For many undergraduates, the research focus on specific applications is important. Not only does it give them concrete examples that align with their individual interests and intuition, but it also motivates the need for deeper and more abstract mathematics. Moreover, through the use of numerical computation, we have found that students can be quickly trained to begin research projects and as they develop computational expertise, they find themselves well-equipped to meaningfully contribute to the overall research program.

The aim of IDeA Labs, however, is more than simply using applications as specific examples for the mathematics of information, dynamics, and control. The real impact emerges when several application areas are engaged simultaneously. Projects from IDeA Labs feed our undergraduate and graduate mathematical sciences curriculum with examples that cut through application-specific jargon and

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focus attention on the common mathematical themes underlying seemingly disparate problems. Mathematical science students with interests in computational biology, ecological dynamics, finance, economics, operations research, engineering, and the policy sciences all take a common core of courses that focus on the mathematical issues surrounding the formulation and computation of decision processes; examples include courses in dynamical systems, modeling & simulation, numerical analysis, and probability & statistics. Introducing application-specific laboratories for student researchers allows us to keep the curriculum focused on the central theory at the intersection of all of these applications, and does so without sacrificing the pedagogical advantage of concrete examples used to feed a wide variety of student interests. Moreover, engaging all of these application areas simultaneously keeps the curriculum focused on the underlying theoretical principles rather than allowing it to become dominated by any one particular application.

2. Central Theme: Algorithmic Decision Processes

Research in algorithmic decision processes is the study of the dynamics of systems that process information to make decisions. Decision systems are ubiquitous, arising everywhere from the strategies deployed by sports teams to investment decisions made by fund managers, and from regulatory signals deployed in metabolic networks to policy decisions made by governments. These processes become algorithmic when an effort is made to make the decisions scientifically, that is, based on data.

Such processes historically have been decomposed into a sequence of stages: modeling, parameter estimation, control, and verification. Although various disciplines have different names for these stages, virtually all scientific decision processes generate a model, parametrize this model using part of the available observation data, use this model to select a decision that is acceptable or optimal according to some objective or measure, and then use the remaining data to verify that the model and/or decision is adequate. As students strip away the jargon of various fields and focus on these scientific decision process, they will discover the universality and importance of abstraction in the mathematical sciences. Through the algorithmic development of decision processes, students will discover the fundamental relationships between information, uncertainty, and complexity that govern the transformation of data into useful decisions.

3. Schedule, Goals, and Activities

Our CSUMS program commences on the first day of the summer term and concludes the following year at the end of the spring term. This allows for intensive 8-week blocks of time at both the beginning and the end of the program so that the students will have time to focus both on (i) learning how to do research at the beginning of the program and (ii) finalizing their projects at the end. It also allows students to take courses in the spring term, before the program begins, if desired or necessary.

The program schedule is broken down into the following periods:

- Summer Workshop (4 weeks)
- Summer Research Immersion (4 weeks)
- Fall Semester (15 weeks)
- Winter Semester (15 weeks)

- Spring Wrap-up (8 weeks)

During each period there are goals and activities that are in place to help insure that students are learning and progressing at each stage in their research, as well as developing good working relationships with those in the group. At the end of each period, we review each student's progress, and meet with them to discuss the review and have an open discussion with the student about their experience in the program.

In order to facilitate positive and open interaction we also have social activities, approximately one activity per period. For example, we kick-off the program with an opening social so that students can get to know us and each other. Then throughout the program we have other activities to further strengthen the overall group dynamic.

Below we outline the goals and activities of each period in the program.

3.1. Summer Workshop (4 weeks). The purpose of the Summer Workshop is to get the students ramped up to do research. Activities are broken up into morning classroom instruction and afternoon computing assignments. Class instruction is given by PI's, senior personnel, graduate students, and guest lecturers. Afternoon computer assignments then provide time for the students to develop computational skill and to also work on their own and in groups.

Classroom instruction starts with more advanced topics from linear algebra, probability and statistics. Care is taken to point out how interconnected these three subjects are. For example, regression is reviewed as an application of least squares, principal component analysis is presented as an application of the singular-value decomposition. Next, students will explore dynamical systems and control, but from a perspective that combines together discrete and continuous dynamics, as well as both deterministic and stochastic modeling. The summer workshop then concludes with an exploration into estimating model parameters from data through state estimation (e.g., Kalman filters), Bayesian methods, time series, and system identification.

In conjunction with BYU's REU program, the summer workshop also has a joint career development seminar, which includes panel discussions and talks from guest speakers on "Misconceptions about graduate school," "How to write a paper," "How to use LaTeX," "How to read a research paper," and "How to use the library and Internet to do research." We have found such career developing experiences to be helpful to students starting research program and it better prepares them for graduate school.

3.2. Summer Research Immersion (4 weeks). The purpose of the Summer Research Immersion is to get students to the point where they are making progress on their research before the academic year begins. During this period, we formally lay the groundwork for student projects. Each student is assigned two projects, according to their interest and input, one where they are the lead investigator and another where they are supporting another student's project. The goal is for each student to be working on projects in both emphasis areas, and to also build a better group environment.

Once projects are selected, we have regular meetings at the project level and at the cohort level. At the start, meetings are held on a daily basis, and as students progress through this period, meetings drop down to a weekly basis. It is hard to have more than one cohort meeting per week once classes begin in the fall, and so it is important for students to develop some independence during the Immersion period so that they are able to make good use of their time during the school year.

It is our philosophy that every meeting should close with a discussion of the goals and deliverables for the next meeting so that students have something on which to focus. For example, at every cohort meeting we will expect one of the students to present something to the entire group.

During the Immersion, students begin outlining their projects doing literature searches. They start modeling and simulating simplified examples and toy models related to their research project so that they build intuition. We have daily project and cohort meetings at this early stage.

As the Immersion period evolves, meeting frequency gradually shifts from daily to a couple meetings per week. The final meeting of the period will conclude with a discussion of project and cohort goals for the rest of the program.

3.3. Fall and Winter Periods (15 weeks each). The goals for the Fall period are to develop the core research methodologies, create an algorithmic decision process, and apply it to a research problem. At the end of the Fall period, each student presents a 15-minute talk to the cohort on their main project.

The goals of the Winter period are for the students to generalize their work as far as possible and to give a talk on their work at our college's Spring Research Conference in mid-March. Students then investigate the implications of weakening constraints and/or hypotheses, and they attempt to connect their work to the broader literature.

Throughout the Fall and Winter periods, we continue have weekly project and cohort meetings so that students can get the feedback that they need, as well as continue to develop the broader familiarity with algorithmic decision processes by exposing them to the other projects in the cohort.

The Spring Research Conference is a great opportunity for students to give a talk and get good feedback from faculty judges and organizers. For many students in the cohort, it is their first talk. One of the purposes of having students present to the entire cohort at our weekly meetings is to give them some experience speaking about their research. The Spring Research Conference extends that to a more general audience. Students are then be able to make improvements to their talks and give their "final" program talk at a professional meeting, e.g, the American Controls Conference, in the summer.

3.4. Spring Immersion and Wrap-up (8 weeks). The purpose of the Spring Immersion and Wrap-up period is to give students time to focus intensely on their projects at the end of the school year, and to wrap up their work into a final report or journal paper. This is a hard process for many students and so much guidance will be needed. After extensive editing and input from faculty, students are expected to submit their work in an appropriate refereed journal or conference venue. An additional benefit of having students work on two projects at once is that some research directions can hit a dead end, or the student might need more time to strengthen their results. This way, they are still able to participate in a conference and/or have a publication in progress at the end of the program year.

4. Student Recruitment and Selection

We are primarily interested in recruiting students who are nearing the end of their sophomore year (or those who have two more years left in their undergraduate education). Our reasoning is that we want students to complete their experience in the cohort before solidifying graduate school and/or career plans. This allows for the full advantage of the experience to have taken effect.

Students apply for the program at the beginning of each calendar year. Application information and a description of the program can be found on the IDeA Labs website (see `idealabs.byu.edu`). To keep the applicant pool high, we also advertise aggressively. In conjunction with other efforts in the math department to bolster our recruitment of students, including women and minorities, we also email all incoming freshman who score highly on the SAT and ACT exams describing the program and outlining the courses that should be taken by the end of their second year. Along these lines, we visit the "Seminar for Women in Math, Science and Engineering" and talk about IDeA Labs in an effort to recruit women into the math and statistics departments, and then into IDeA Labs. Finally, mathematical sciences students from underrepresented groups, including women, will be personally contacted through email and invited to apply.

Students selection is based on (i) course-work preparation, (ii) potential for success, (iii) evidence of work ethic, (iv) curiosity, (v) attitude, (vi) citizenship, and (vii) diversity.

5. Project Evaluation and Reporting

5.1. Quality Control. We have organized a network of 18 advisers and reviewers who will help to insure that our program running well. With each person, we have discussed the scope and vision of IDeA Labs and have received warm responses, good feedback, and an eager willingness to assist.

We have recruited two BYU faculty members to be overall program reviewers to help us with the recruitment, selection, and mentoring of women. Both have agreed to annually review our program provide us with helpful feedback.

In an effort to insure quality of our work at IDeA Labs, we have developed a team of research area advisers and reviewers. Each lab will have (i) an internal adviser, (ii) an internal reviewer, (iii) an external reviewer, and (iv) an industrial reviewer.

The purpose of the internal adviser is to provide the PIs with subject-matter expertise in each particular field. Our interactions with them help us to better guide students into projects that are current with the mainstream thought and the cutting-edge ideas. In fact all four advisers have expressed an interest in working with us on projects. In fact, one remarked to us after reviewing our students' work in the area that our undergraduates were more capable of doing research in his field than his own masters students because they lacked the mathematical and computational skill necessary to help carry out the work.

The purpose of the three reviewers is to biennially visit the labs and to write-up a formal review with recommendations. Reviewers will also be given a questionnaire to help solicit specific feedback about our program. By design, each reviewer comes from a different vantage point. Internal reviewers are able to uniquely offer advice that's coupled with institutional knowledge of BYU, external reviewers add intellectual diversity into their feedback, and industrial reviewers are able to provide feedback that will help us to strengthen our industrial partners program. In addition to good evaluation and reporting, an additional benefit of having a team of advisers and reviewers is that they are all be well-positioned to write letters of recommendation on behalf of our students when they apply to graduate schools.

5.2. Key Performance Indicators. Key performance indicators are collected and reported in an effort to evaluate the output of this program and its overall benefit. For example demographic data is collected and broken down, research activities summarized, and class enrollments tabulated. Quantitative measures of undergraduate research is also collected, including numbers of participants, academic presentations, publications in refereed venues, and additional support through grants and gifts are noted.

Following the lead of [**1**], surveys are administered at the beginning of the program, at the end of the program, and the following two years after the project concludes. Questions gauge courses taken, future courses planned, and hours per week spend doing mathematics outside of coursework. Questions regarding graduate school and career interests are included.

As described above, students are reviewed 5 times during the cohort year, and the review is shared with them so that they can improve. Through that process, we also get qualitative feedback from students so that we can continue to improve the overall CSUMS mentoring experience.

References

[1] A. Adhikari and D. Nolan, "But what if good came at last" How to asses the value of undergraduate research. Notices of the AMS 49:1252-1257, 2002.

Department of Mathematics, Brigham Young University, Provo, UT 84602
E-mail address: jeffh@math.byu.edu, sean@cs.byu.edu